EVALUATION OF SPEECH PROCESSING FOR TELEPHONE USE BY OLDER ADULT LISTENERS WITH HEARING LOSS

A Capstone Project

Presented in Partial Fulfillment of the Requirements for

The Degree Doctor of Audiology in the

Graduate School of The Ohio State University

By

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The Ohio State University
2007

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ABSTRACT

Telephone communication is a significant difficulty for many older adults with hearing loss. Due to communication difficulties that counselors at the Franklin County Office on Aging experienced with many callers with hearing loss, The Ohio State University Department of Speech and Hearing Science and the Department of Electrical and Computer Engineering developed a speech enhancement algorithm. This algorithm pre-processes speech on the talker's end before being sent over the telephone line. Twenty older adults with hearing loss participated in Experiment 1 of this study to determine the best speech intelligibility test (phoneme-based test, sentence test, or signal-to-noise ratio [S/N] test) for evaluating the performance of older adult listeners with sensorineural hearing loss over the telephone. Results revealed an improvement in speech perception with processing and indicated that the representative S/N test, the Quick Speech in Noise test, was the most effective and efficient test for this evaluation. Thirty older adults participated in Experiment 2, which verified that the commercial version of the speech processing algorithm led to an improvement in the speech recognition abilities of older adults over the telephone, and confirmed that this improvement was equal to the improvements resulting from the laboratory version.

Dedicated to My Parents, Ed and Kathy Harhager

ACKNOWLEDGMENTS

I extend my sincere appreciation to those who provided their help and support to assist me in the completion of this capstone project. I thank Dr. Stephanie Davidson for serving as my academic advisor and for providing me with guidance throughout the processes of completing my capstone project. I thank Dr. Lawrence Feth for sharing his knowledge of the speech-processing algorithm and for inviting me to become a part of this research project. I thank Dr. Jeanne Gokcen and FutureCom Technologies, Inc. for their work on the speech processing algorithm and the recordings of test materials. I also thank my parents for instilling the importance of education in me and providing me with support throughout my educational career.

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Telephone communication is difficult for many older adults with hearing loss. Various factors contribute to the difficulties experienced during telephone use in addition to the individual's hearing loss, including the limited frequency range available over the telephone, absence of visual cues, line noise that is present at the receiver, background noise, and monaural listening. Due to communication difficulties that counselors at the Franklin County Ohio Office on Aging experienced with many callers with hearing loss, a speech enhancement algorithm was developed through a collaborative effort of The Ohio State University Department of Speech and Hearing Science and the Department of Electrical and Computer Engineering. This algorithm pre-processes speech on the talker's end before being sent over the telephone line to the listener with hearing loss.

This capstone project involved a continuation of previous research, serving two main purposes, or objectives. The first objective was to determine the best speech intelligibility test (phoneme-based test, sentence test, or S/N test) for evaluating the performance of older adult listeners with sensorineural hearing loss over the telephone. Due to plans for the algorithm to be implemented in a commercial product, the second objective was to verify that the commercial version of the speech processing algorithm led to an improvement in the speech recognition abilities of older adults over the telephone, and to confirm that this improvement was equal to the improvements resulting from the laboratory version.

1.1 Hearing Loss Overview

Hearing loss has become a difficulty for many individuals due to aging, noise exposure, heredity, ototoxicity, and other conditions. Prior to discussing the negative impact that hearing loss can have on communication, it is important to have a general understanding of hearing loss. Two main factors can be used to describe an individual's hearing loss. These factors are type and degree.

There are three types of hearing loss: sensorineural, conductive, and mixed. Sensorineural hearing loss can be defined as a decrease in hearing sensitivity due to disorders of the cochlea or the eighth cranial nerve. In general, sensorineural hearing losses are not medically or surgically correctable. Because of this, hearing aids are a common recommendation for this type of hearing loss. Conductive hearing loss can be defined as a decrease in hearing sensitivity due to impaired sound transmission through the outer and/or middle ear, while the inner ear remains normal. In many cases, conductive hearing losses can be medically or surgically corrected. Finally, a mixed hearing loss has both conductive and sensorineural components.

In addition to the type of hearing loss, the degree of loss is also important for describing one's hearing abilities. The degree of hearing loss can be defined as the severity of the hearing loss. The degrees of hearing loss range from mild to profound. In general, the greater the hearing loss, the more difficulty an individual will have with communication. The degrees of hearing loss are defined in Table 1.

Degree	Hearing Level
Normal Hearing	-10 to 15 dB HL
Slight Loss	16 to 25 dB HL
Mild Loss	26 to 40 dB HL
Moderate Loss	41 to 55 dB HL
Moderately-Severe Loss	56 to 70 dB HL
Severe Loss	71 to 90 dB HL
Profound Loss	> 90 dB HL

Table 1.1: Degree of Hearing Loss Classifications (Harrell, 2002).

1.2 Hearing Loss and Older Adults

Of the chronic conditions affecting the older adult population, hearing loss is ranked as the third most common (Weinstein, 2000; American Academy of Audiology [AAA], 2007). In addition, the United States is undergoing a significant change in the age distribution of the population. This change involves an increase in the number of older adults, or those 65 years of age and older. According to The American Academy of Audiology Task Force on Hearing Impairment in Aged People, the 65 and older age group is growing more rapidly than any other age group in the United States population (AAA, 2007). Therefore, the number of cases of presbycusis, or hearing loss associated with aging, can be expected to rise. It is estimated that 21 million older adults will have hearing loss by the year 2030 (Garstecki, 1996; Weinstein, 2000).

1.2.1 Presbycusis and Age-Related Changes in the Auditory System

Presbycusis is the "sum of hearing losses which result from several varieties of physiological degeneration" including noise exposure, medical disorders, ototoxicity, polypharmacy, and physiological aging (AAA, 2007). Several anatomical and physiological changes occur in the auditory system as a result of aging. These changes can occur in the peripheral and/or central auditory system.

Changes to the outer ear can include loss of pinna elasticity and narrowing of the ear canal. In the middle ear, the tympanic membrane may become more rigid and ossicular atrophy may occur. In the inner ear, changes may include extensive atrophy and degeneration of the hair cells and the Organ of Corti, and decreased elasticity of the basilar membrane. Changes in the central auditory system can include a loss of neurons in the brain, atrophy of the cortex, decreased blood flow, and decreased wave capacity (Heine & Browning, 2002).

1.2.2 Social Consequences of Hearing Loss

Older adults may experience impacts on their quality of life and feelings of well-being due to hearing loss. Hearing loss can interfere with the reception of spoken messages, leading to frequent communication breakdowns. In turn, a limited ability to repair communication breakdowns due to personal, situational, and environmental factors frequently results in poor psychosocial functioning (Heine & Browning, 2002). According to Heine and Browning (2002), "one of the major consequences of …hearing loss is poor psychological functioning and disruption of social behaviour," including a loss of independence in daily life (p. 767). In addition, hearing loss can lead to social withdrawal, isolation, depression, anxiety, lethargy, and social dissatisfaction if the older individual has difficulty adjusting to the hearing loss (Garstecki & Erler, 1998; Heine & Browning, 2002).

1.3 Telephone Communication and Hearing Loss

Telephone communication is important for older adults. It empowers these individuals “to conduct their own business and personal activities” (Cray, Allen, Stuart, Hudson, Layman, and Givens, 2004, p. 200). The ability to communicate over the telephone promotes independent living and socialization. In turn, it promotes a healthy self-esteem (Cray et al., 2004). Telephone use also aids in the safety of older adults at home. The Franklin County Ohio Office on Aging (FCOA) provides a Home Safety Checklist for older adults, which includes access to a telephone in case of emergency and the posting of emergency numbers near the telephone as two main points (FCOA, n.d.).

For individuals with hearing loss, telephone communication can be very difficult due to several factors. According to Kepler, Terry, and Sweetman (1992), there are three major factors that contribute to the difficulties in speech understanding that individuals with hearing loss experience over the telephone, including the limited frequency range available over the telephone, absence of visual cues, and the hearing loss of the listener. First, the limited available frequency range of approximately 300-3500 Hz reduces the amount of high frequency speech information that is carried over the telephone. This can lead to difficulty communicating over the telephone because these high frequencies are important for speech intelligibility (Kepler et al., 1992; Rodriguez, Holmes, DiSarno, & Kaplan, 1993).

Listening over the telephone also involves an absence of visual cues. The listener must rely solely on auditory cues to understand the speech signal (Kepler et al., 1992). According to Heine and Browning (2002), "the visual channel is important for the reception of non-verbal cues and gestures such as lipreading, contextual cues, pragmatic markers, facial expressions and eye-gaze" (p. 766). Visual information from the face is particularly effective when noise, limited bandwidth, or hearing loss degrade the auditory signal (Massaro & Light, 2004). Because individuals with hearing loss use visual cues to compliment auditory cues, the absence of visual cues on the telephone can negatively affect communication.

The third factor, according to Kepler et al. (1992), is the hearing loss of the individual that leads to a reduced audibility of the telephone signal. Cray et al. (2004) indicate that the ability to effectively communicate using the telephone decreases as the severity of the hearing loss increases. Line noise that is present at the receiver can cause further distortion of the telephone signal (Rodriguez et al., 1993). In addition to these factors, the listener's speech understanding abilities can be negatively affected by background noise in the listener's environment and the fact that the signal is presented to only one ear.

1.4 Hearing Aids and Telecoils

According to the American Academy of Audiology (AAA), "evidence indicates that hearing aids successfully reduce the social, emotional, and functional handicap often resulting from hearing impairment in aged people" (AAA, 2007). One optional feature that is available in many hearing aids is the telecoil, which is used to assist in telephone communication. A telecoil is an induction coil, or metal rod encircled by a looped copper wire, that is built into the body of the hearing aid. When placed in a magnetic field created by a hearing aid-compatible telephone, the coil converts the magnetic energy into electrical energy, while maintaining the original speech information (Ross, 2002). Telecoils can be used to amplify speech over the telephone efficiently while background noises around the listener are better reduced (ASHA, 2007). Therefore, hearing aids can be used to help make speech over the telephone clearer.

Although hearing aids can improve speech understanding over the telephone, not everyone who can benefit from hearing aids uses them. Only approximately 22% to 24% of individuals with hearing loss own and use hearing aids (Cox, Alexander, & Gray, 2005; English, Lucks Mendel, Rojeski, & Hornak, 1999; Garstecki, 1996). This means that 16 million older adults who could benefit from hearing aids will not use them if these hearing instrument market penetration rates remain stable (Garstecki, 1996).

Several key factors have been cited as influencing hearing aid use, including the severity of hearing loss, cost of the instruments, limitations in current technology, lack of support from health care providers, negative stigma that is often associated with hearing aids, and perceived benefit (Garstecki, 1996; Garstecki & Erler, 1998). In addition, vanity issues and undiagnosed hearing loss can also influence the use of amplification. In a study by Garstecki and Erler (1998), a number of older adults with hearing loss reported not wearing hearing aids due to the beliefs that hearing instruments communicate weakness and signal the onset of aging. In addition, this group indicated that hearing aids indicate that an individual is less intelligent, less attractive, and has negative personality traits (Garstecki & Erler, 1998).

1.5 Background and Motivation

The Franklin County Ohio Office on Aging (FCOA) contacted The Ohio State University Department of Speech and Hearing Science in the late 1990s to express an interest in developing a way to assist their counselors in communicating with older adults with hearing loss over the telephone. The FCOA provides access to diverse programs and services for older adults and their families so they can preserve their independence and quality of life (FCOA, 2004). The FCOA has offered the Senior Options Program since 1993. This program provides Franklin County residents 60 years of age and older with services such as medical transportation, home delivered meals, and minor home repair (FCOA, 2004).

1.5.1 Speech Processing Algorithm

In response to the FCOA's request, a speech enhancement algorithm was developed by The Ohio State University Department of Speech and Hearing Science and the Department of Electrical and Computer Engineering to ease communication over the telephone. The resultant speech enhancement system pre-processes speech before being sent over the telephone line. It was designed to compensate for the limited bandwidth of the telephone and the listener's hearing loss. The current speech enhancement algorithm was designed to use an average audiogram of fifty older adults (74 to 93 years of age) referred to and tested at the Columbus Speech and Hearing Center between 1996 and

2000 (Komattil, 2004). The goal of this speech enhancement algorithm was to use compression amplification to improve intelligibility within the limited bandwidth of the telephone (Poling, 2004).

The average hearing loss from the fifty older adults tested at the Columbus Speech and Hearing Center is shown in Figure 1.1 (dotted line). The average thresholds were increased at 2 kHz, 3 kHz, and 4 kHz due to the roll-off of the frequency response of the telephone that is present above 2 kHz. These thresholds were changed to compensate for the effect of the phone line because this roll-off introduces additional "hearing loss" at these frequencies. The resultant modified audibility curve is also shown in Figure 1.1 (solid line).

Additional details of the algorithm were provided in an unpublished master's thesis. According to Natarajan (2002), the algorithm processes the speech signal based on the level of the signal and the threshold parameters of the average audiogram. Using the multi-channel dynamic range compression algorithm, gain is determined based on the level of the speech signal. Relatively more gain is applied to the less intense components of speech than to the more intense components of speech, while keeping the amplitude of the signal across all frequencies within the dynamic range available for telephone transmission.

In addition, the speech signal is enhanced by the speech enhancement algorithm to compensate for the steep roll-off on the frequency response of the telephone above 2 kHz. This roll-off occurs because the telephone can introduce nonlinearity by clipping the signal, because the signal is beyond the available amplitude range of the telephone. This roll-off on the frequencies above 2 kHz can simulate additional hearing loss in the 2

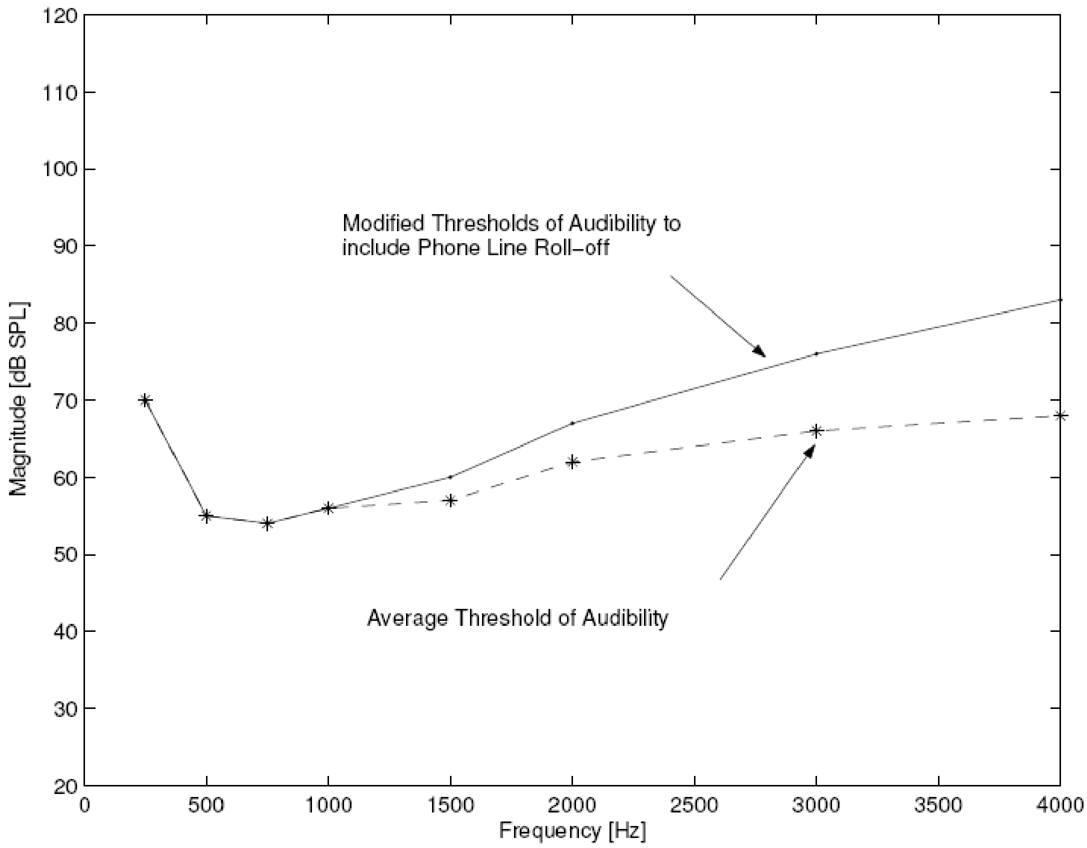

Figure 1.1: Average Audibility Thresholds and Modified Average Thresholds. The average threshold of audibility curve (dotted line) is the average of audiograms of fifty older adults. The modified thresholds of audibility (solid line) is the average audiogram compensated for the phone line frequency roll-off. Figure from Komattil (2004).

to 4 kHz region (Natarajan, 2002). Therefore, additional gain is provided between 2 and 4 kHz to compensate for this additional loss from the limitations of the telephone line. “A multi-channel frequency-domain dynamic range compression algorithm to match the speech signal to the reduced dynamic range of the listener with hearing loss was the final product” (Poling, 2004, p. 18).

It has been shown that speech intelligibility can be improved by preserving spectral contrast during processing. Although it is not possible to maintain spectral peak-to-valley ratios throughout the frequency range of interest in a multi-band compression system, this speech-processing algorithm attempts to preserve the contrast in the bands around the important formant frequencies. The main steps of the speech-processing algorithm are summarized in Figure 1.2. First, the original speech signal is divided into 32 ms frames with 50% overlap between successive frames (Natarajan, 2002). Second, channels are identified based on the spectral content of each frame. The spectral information in each frame is obtained by computing the Fast Fourier Transform of each frame. Further processing is applied only to frames that are identified as having speech information. If the frame is determined to be below a noise threshold, it is classified as “non-speech” and no gain is applied. Next, the average spectrum levels are obtained for each critical band in each frame. These integrated spectrum levels are then passed through a peak detection module. The three most intense peaks are used in identifying the channels. The channel locations and bandwidths vary across time so that the three major peaks, corresponding to formant frequencies, are as far away from channel boundaries as possible. “This dynamic channel identification preserves spectral contrast around important frequencies by positioning the channels based on the spectral content of the frame and hence provides a frequency-dependent compression technique" (Natarajan, 2002, p. 29).

Third, gains are determined to preserve spectral contrast. The compression ratio applied to each channel is calculated based on the average threshold of the model audiogram in that channel along with the spectrum level (Natarajan, 2002). Fourth, gains are smoothed across frames. Gains need to be constrained using attack and release constraints (attack and release from compression) to avoid allowing the gain to vary too quickly across the frames. These constraints are applied to each channel across frames because fast variations in gain may become uncomfortable for the listener.

Finally, frames are transformed into the time domain and processed speech is obtained. Processed speech is obtained in each frame using the Inverse Fast Fourier Transform (IFFT). An "overlap-add technique" is used to combine the frames and obtain the complete processed speech signal (Natarajan, 2002). Work by Komattil (2004) allowed for the pre-processing algorithm to be used in near real-time, processing speech as it is spoken into a microphone with a delay of 16 ms.

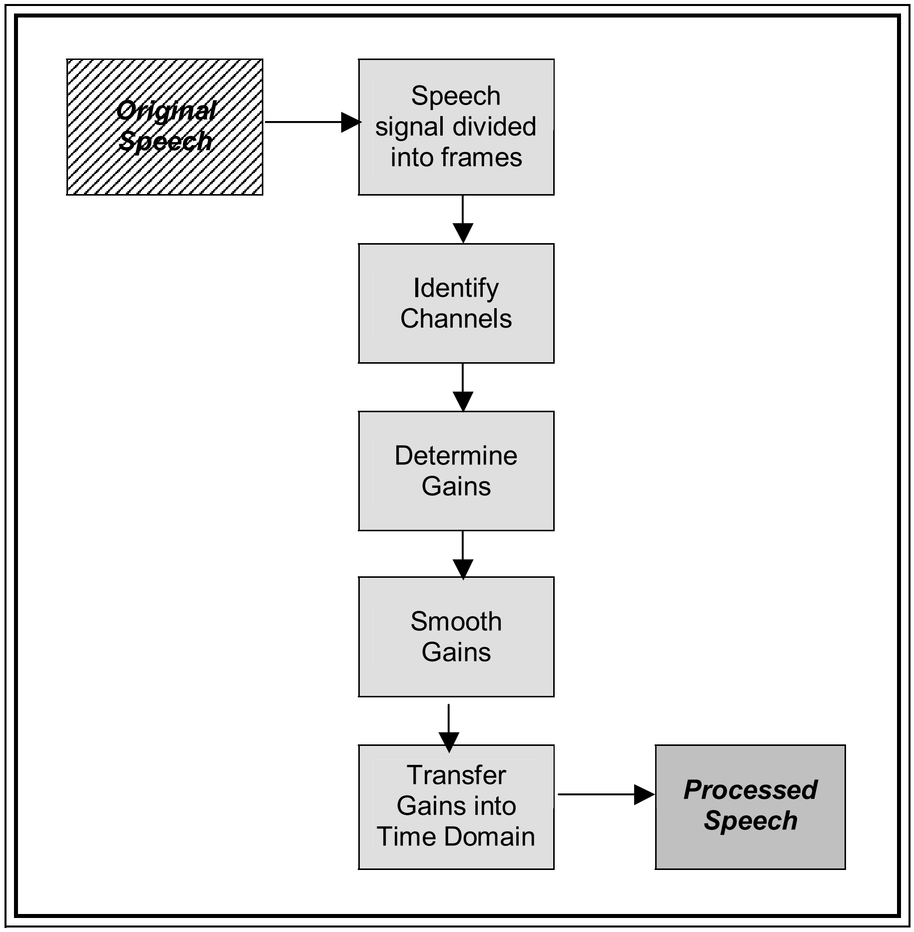

Figure 1.2: Main Modules of the Speech Processing Algorithm (Natarajan, 2002).

1.5.2 Previous Research

Natarajan's (2002) research included testing the speech-processing algorithm on eight subjects. Subjects were between 22 and 55 years of age and had normal hearing. The processed speech signal was passed through a hearing loss model to simulate hearing loss before being presented to the listener. Sentences from the Speech Perception in Noise test (SPIN; Bilger, Nuetzel, Rabinowitz, & Rzeczkowski, 1984) were used to assess speech understanding in the processed and unprocessed conditions. Improvement in speech intelligibility was found for the processed speech (Natarajan, 2002). Results from this study were promising; however, a major limitation of the algorithm existed. The algorithm operated on recorded stimuli only. To address this limitation, Komattil (2004) implemented the speech processing algorithm in near real-time to allow for processing of a speech signal as it was spoken or played via computer files.

Using Komattil's (2004) processing, Poling (2004) performed a pilot study on five older adults diagnosed with sensorineural hearing loss. Figure 1.3 shows the average audiogram used for subject recruitment. In addition to having a moderate sensorineural hearing loss, subjects were required to be 60 – 70 years of age. She tested the effectiveness of this speech enhancement device at improving telephone communication using three types of speech understanding tests. These included a phoneme-based test, a sentence-based test, and a signal-to-noise ratio (SNR) test. The California Consonant Test (CCT; Owens & Schubert, 1977) was used as the representative phoneme-based test. The Speech Perception in Noise test (SPIN; Bilger, et al., 1984) was used without the multi-talker babble for the sentence test. Finally, the Quick Speech in Noise test (QSIN; Killion, Niquette, Gudmundsen, Revit, & Banerjee, 2003) was used as the representative

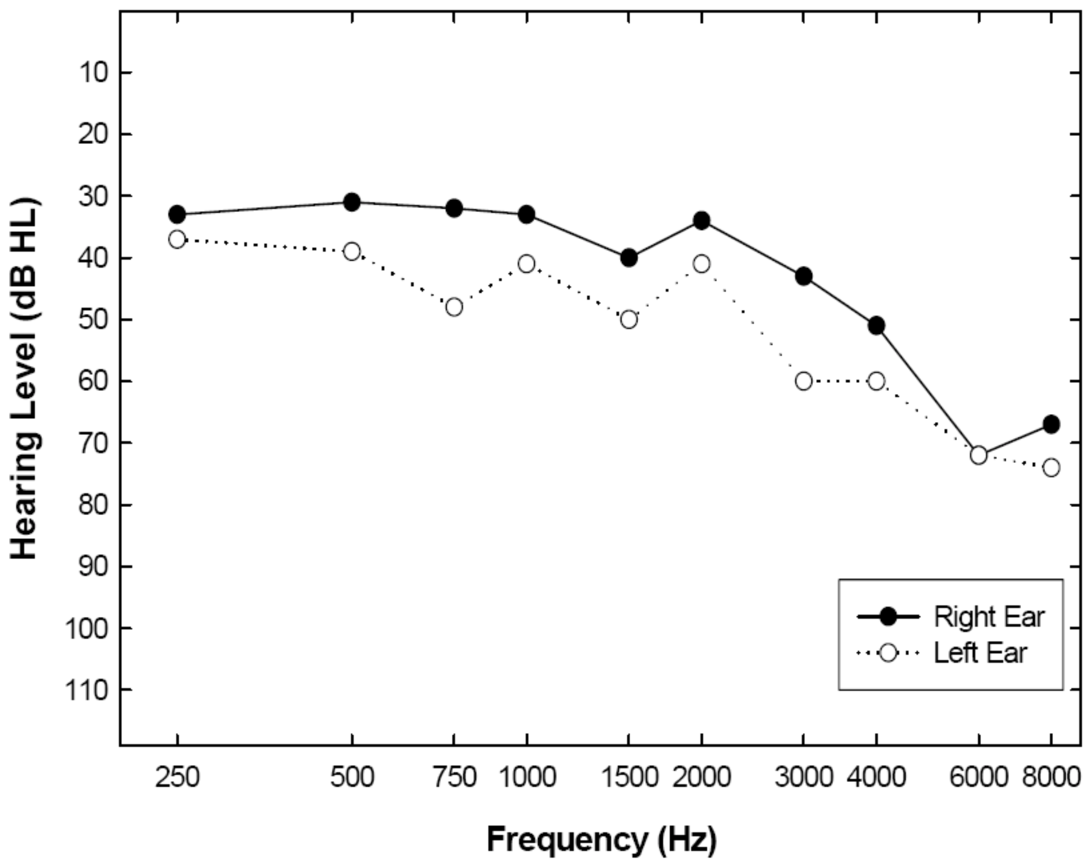

Figure 1.3: Average Audiogram used for subject recruitment by Poling, 2002. The average hearing loss is from 18 individuals aged 60 – 70 years from the Senior Options Program of the FCOA. Individuals were tested at the Columbus Speech and Hearing Center. Figure from Poling (2004).

SNR test. An increase in speech understanding with processing was found for all three tests, however, one showed significantly more improvement than the others. It was found that the QSIN was the most appropriate assessment tool because it measured the greatest improvement in the subjects' speech understanding over the telephone (Poling, 2004).

1.6 SBIR Grant and Research Objectives

Due to the positive results of Poling's (2004) study, the idea of commercializing the speech-processing algorithm arose. FutureCom Technologies, Inc., in conjunction with The Ohio State University Departments of Speech and Hearing Science and Electrical and Computer Engineering, applied for and received a Phase I Small Business Innovative Research (SBIR) grant from the National Institutes of Health (NIH). Phase I of the SBIR project included three objectives. First, FutureCom Technologies aimed to "demonstrate the feasibility of integrating the telephone speech enhancement system into a commercial system" (Gokcen, 2006, p. 3). The second and third objectives were the focus of this capstone project and described below.

The first objective of the present study was to determine the best speech intelligibility test (phoneme-based test, sentence test, or S/N test) for evaluating the performance of older adult listeners with sensorineural hearing loss over the telephone. The second objective of the present study was to verify that the commercial version of the speech-processing algorithm led to an improvement in the speech recognition abilities over the telephone, and to confirm that this improvement was equal to the improvements resulting from the laboratory version.

CHAPTER 2

METHODS AND RESULTS – EXPERIMENT 1

The objective of Experiment 1 was to determine which type of speech intelligibility test served as the best tool for evaluating the performance of older adult listeners with hearing loss over the telephone. This chapter describes the participants, calibration, and procedures used for Experiment 1. In addition, the data processing involved and results of this experiment are reported.

2.1 Participants

Twenty participants (9 male, 11 female) were recruited for Experiment 1 from The Ohio State University using the Speech and Hearing Clinic database and employee email advertisements. A recruitment letter (Appendix A) was sent to potential subjects identified through the database to inform each person that he or she may be a candidate for the study and that a doctoral student would be calling to determine interest and answer questions. Oral scripts (Appendix B) were used during these phone calls. Potential subjects were also recruited from advertisements in OSU Today, a daily Ohio State University employee email, which asked them to contact the doctoral student through email if interested in participating (Appendix C). In addition to these methods, a flyer was posted in the Speech and Hearing Clinic waiting room, which asked interested patients to contact the doctoral student over the telephone (Appendix D).

Participants were 55 to 70 years of age, native speakers of English, and had moderate to severe sensorineural hearing loss in at least one ear. Listeners received a free hearing evaluation and a monetary payment for their participation in this experiment.

2.2 Procedures

2.2.1 Forms

Prior to testing during the first session, the participants were given forms to read and sign. These included the Consent for Participation in Social and Behavioral Research (Appendix E) and the Authorization to Use Personal Health Information in Research (Appendix F).

Subjects were reimbursed for their parking and compensated for their time. For the first session, compensation consisted of a free audiological evaluation. For the second session, compensation consisted of a monetary payment given to the subject at the beginning of the test session. All subjects were also required to sign a Payment Record Form (Appendix G) to reflect these reimbursements and compensations.

2.2.2 Stimulus Materials

Three types of speech intelligibility tests were evaluated in this experiment to determine which type of test served as the best tool for evaluating the performance of listeners with sensorineural hearing loss on the telephone. The best tool was defined as the one that was the most effective at differentiating subjects' performance on unprocessed and processed versions of the test and was the most efficient, or least time-consuming. One representative speech intelligibility test was chosen from each of the following categories – phoneme discrimination tests, sentence recognition tests, and signal-to-noise ratio (SNR) tests. Gokcen (2006, p. 71-72) described each of the three speech intelligibility tests as follows.

> The Modified Rhyme Test (MRT; Kreul, Nixon, Kryter, Bell, Lang, & Schubert, 1968) was used as the representative phoneme recognition test. The MRT is a closed-set 50-item test, with each item consisting of a set of six monosyllabic words that vary in either initial or final consonant. The MRT requires the listener to report the word that he heard by marking the item on a list of six response alternatives.
>
> The Revised Speech Perception in Noise Test (SPIN; Bilger et al., 1984) was used as the representative sentence recognition test. Each SPIN lists consists of 50 sentences, with 25 high context sentences and 25 low context sentences. The high context sentences have final words that are predictable using the cues from the initial portion of the sentence (e.g. "The turtle went into its shell"). The low context sentences have final words that are difficult to predict from cues given in the initial part of the sentence (e.g. "The woman knew about the lid"). The SPIN requires the listener to repeat the last word of each sentence. Although the SPIN was originally designed to be given in the presence of background noise (using prerecorded multi-talker babble), the test was given in quiet for this experiment.
>
> The Quick Speech-in-Noise Test (QSIN; Killion et al., 2003) was used as the representative signal-to-noise ratio (SNR) test. Each QSIN list consists of six sentences with five key words per sentence presented in varying levels of background multi-talker babble (e.g. "Tear a thin sheet from the yellow pad"). The QSIN requires the listener to repeat sentences heard and provides a quick estimate of SNR loss, which is defined as the SNR at which the listener can identify 50% of the key words from the sentence. [Although the QSIN was originally designed for determining the SNR loss, the test was used in this study to determine percent correct score.]

2.2.3 Processing and Delivery of Speech Intelligibility Tests

Each of the speech intelligibility tests (MRT, SPIN, and QSIN) was digitized and stored on a desktop PC hard drive. For testing of listeners with hearing loss, the Ohio State version of the speech-processing algorithm (implemented in MatLab and SimuLink) was used to process tokens from the selected tests. Processed tokens were delivered to the telephone line through a Creative Systems Audigy 2NX sound card and a Gentner telephone coupling device. See Figure 2.1 for details of the setup.

2.2.4 Calibration

Although the FutureCom Technologies CommUnify processing system was not used in Experiment 1, it was used as the "Gold Standard" for calibration of the Ohio State processing system. The signals processed using the Ohio State system were matched to the level of the CommUnify system using the volume control on the Sound Blaster. Single-channel calibration tones were used to avoid doubling of the signal level in the Mixer. Using a sound level meter to measure the level on the listener's telephone, it was determined that the Sound Blaster volume should be set to 42%, as read on the computer screen.

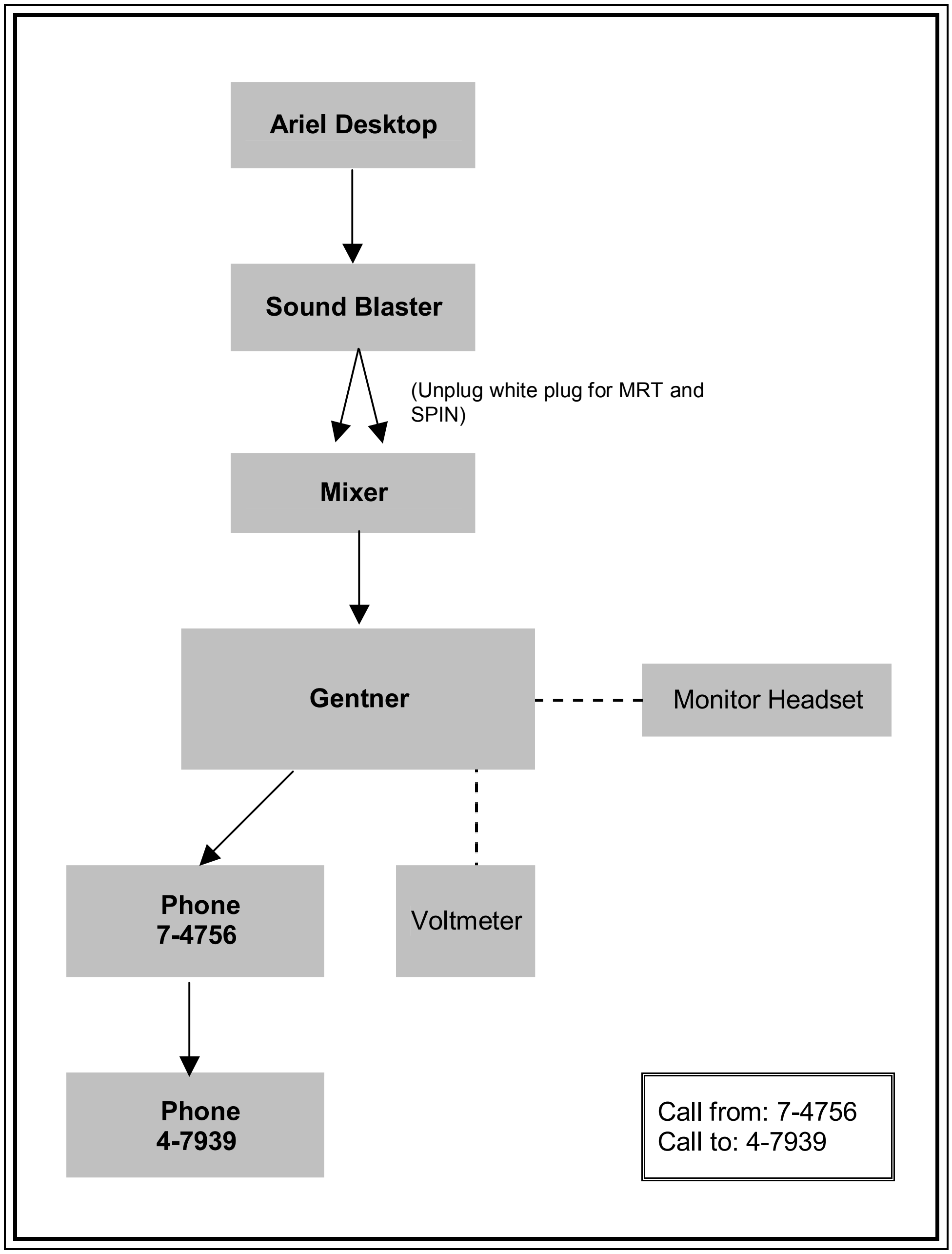

Figure 2.1: Laboratory Setup for Experiments 1 and 2.

2.2.5 Sessions 1 and 2

Testing was completed in two sessions.

- **Session 1: Standard Audiological Evaluation.** To determine eligibility for the study, all participants received a routine audiological evaluation. This evaluation consisted of the following procedures: otoscopy, tympanometry, conventional pure tone audiometry including air and bone conduction thresholds, speech recognition threshold testing, and word recognition testing. All audiometric testing was completed in a sound-treated booth, using standard clinical procedures.
  - Individual audiometric data is shown in Appendix H. An average audiogram from the twenty subjects in Experiment 1 is shown in Figure 2.2.

- **Session 2: Comparison of Speech Intelligibility Tests.** Once the current hearing abilities of the participants were established, each subject listened to processed and unprocessed versions of the three speech intelligibility tests described above. Testing was completed in the Hearing Aid Research Laboratory in Pressey Hall on The Ohio State University campus. Participants were seated in a sound-treated booth, and tests were delivered to a standard telephone receiver over a standard telephone line. The order of test delivery (type of test) was randomized and the presentation mode (processed versus unprocessed) was counterbalanced to prevent order effects.

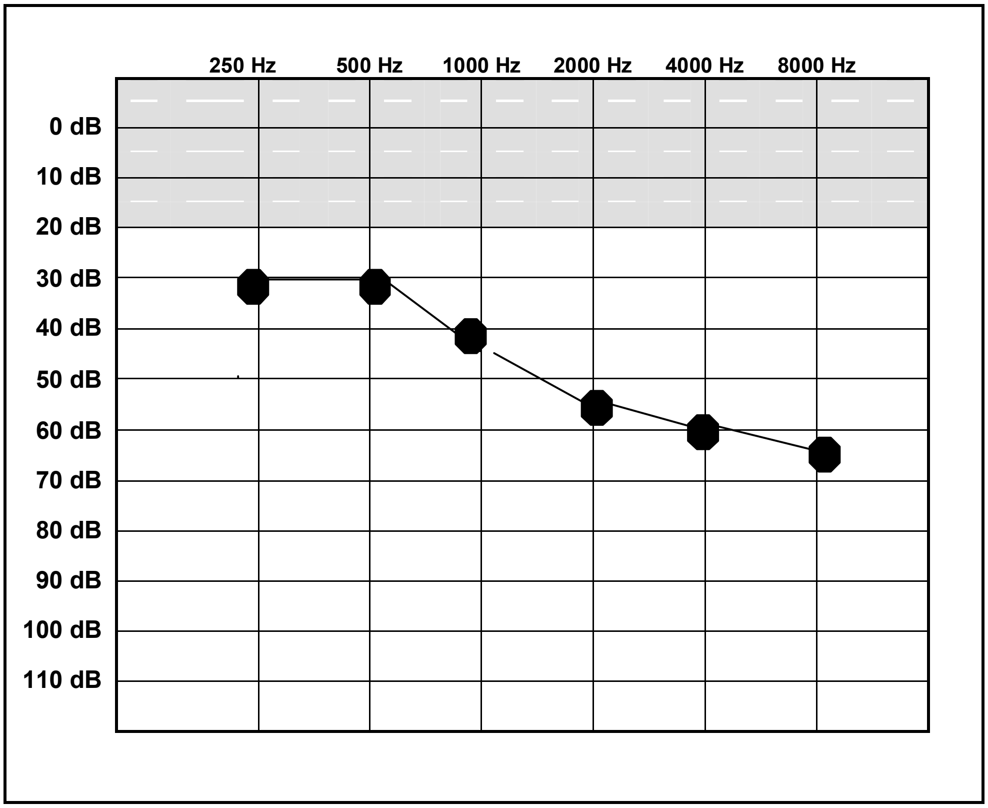

Figure 2.2: Average Audiogram of Experiment 1 Participants (Average of the 20 ears used for experimental testing). Pure tone average (PTA) = 42 dB HL.

2.3 Data Processing and Results

Data from Experiment 1 were used to determine percent correct scores and percent improvement (with processing) scores for each of the twenty subjects included in this portion of the study. Individual scores are shown in Appendix G. In addition, an average percent correct score and an average percent improvement score were obtained for each of the speech intelligibility tests. The average percent correct and percent improvement scores were statistically analyzed to determine if the three speech intelligibility tests resulted in significantly different scores.

2.3.1 Percent Correct: Processed vs. Unprocessed

Figure 2.3 shows the average percent correct score for the unprocessed and processed presentation modes for each of the three tests—MRT, SPIN, and QSIN. The white bars represent the average scores obtained when using the unprocessed versions of the tests and the gray bars represent the average scores obtained when using the processed versions of the test. As can be seen, subjects tended to score better when listening to the processed versions of the all of the tests. The largest difference between scores obtained on the processed and unprocessed versions of the test occurred with the QSIN test. Smaller average differences were noted when using the SPIN and the MRT tests. A ceiling effect was noted for the unprocessed conditions of the MRT and SPIN in the comparison of the speech intelligibility tests, leaving little room for improvement when using the processing algorithm.

Percent correct scores from each of twenty subjects were arc-sine transformed and analyzed using a two-factor (test and presentation mode) within-subjects analysis of variance (ANOVA). A significant (defined as an alpha level of ≤ 0.01) main effect of test was found ($F[2,38] = 133.41$, $p = .000$). Post hoc means comparisons indicated no significant difference between the MRT and the SPIN tests, but indicated significant differences between the QSIN and both the MRT and SPIN tests. The analysis also indicated a significant main effect of presentation mode ($F[1,19] = 89.48$, $p = .000$), indicating a significant improvement in speech perception over the telephone with the use of the processing algorithm. A significant interaction effect between test and presentation mode was found ($F[2,38] = 16.57$, $p = .000$), indicating that the effect of processing was not the same across test types.

2.3.2 Percent Improvement with Processing

A second way to examine the results from Experiment 1 was to look at a percent improvement score across tests. A percent improvement calculation allowed for the examination of improvement in performance from the unprocessed to the processed condition for each of the three tests. Percent improvement scores were devised for each subject for each of the three tests using the following equation, with P(c) representing percent correct:

Percent Improvement = [(P(c) processed – P(c) unprocessed) ÷ P(c) unprocessed] x 100

Figure 2.4 shows the average percent improvement scores for each of the three tests. As could be inferred from Figure 2.3, the QSIN showed the most improvement with processing, followed by the SPIN and MRT.

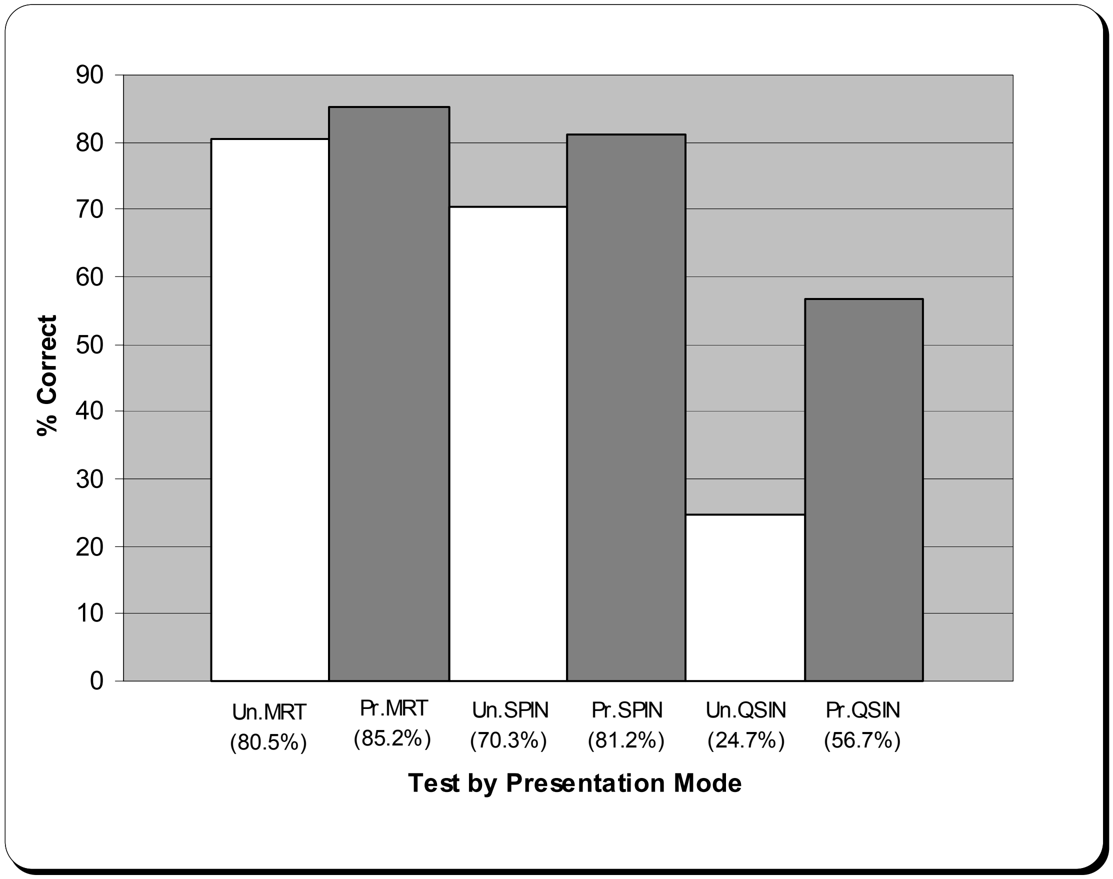

Figure 2.3: Experiment 1: Average Percent Correct Responses for Unprocessed and Processed Presentations for Each Speech Intelligibility Test. White bars represent the unprocessed condition. Dark gray bars represent the processed condition.

Percent improvement scores from each of the twenty subjects were analyzed using a one-factor (test) within-subjects ANOVA. Looking at percent improvement across tests, a significant (defined as an alpha level of = 0.01) main effect of speech intelligibility test was found ($F[2,38] = 8.69$, $p = .001$). Post hoc means comparisons indicated significant differences in percent improvement with processing between each of the three speech intelligibility tests.

Experiment 1 was used to determine which of the three speech intelligibility tests was the most effective and most efficient. The QSIN was determined to be the most effective test, because it best differentiated the subjects' performance on the unprocessed and processed presentations of the speech stimuli. The QSIN was also determined to be the most efficient test, because it was the least time consuming of the three speech intelligibility tests (the SPIN test took the longest at 10 minutes per test; the MRT was next at 6.5 minutes per test, and the QSIN was completed in the least amount of time at 1.5 minutes per test). Therefore, the QSIN was the speech perception test used in Experiment 2.

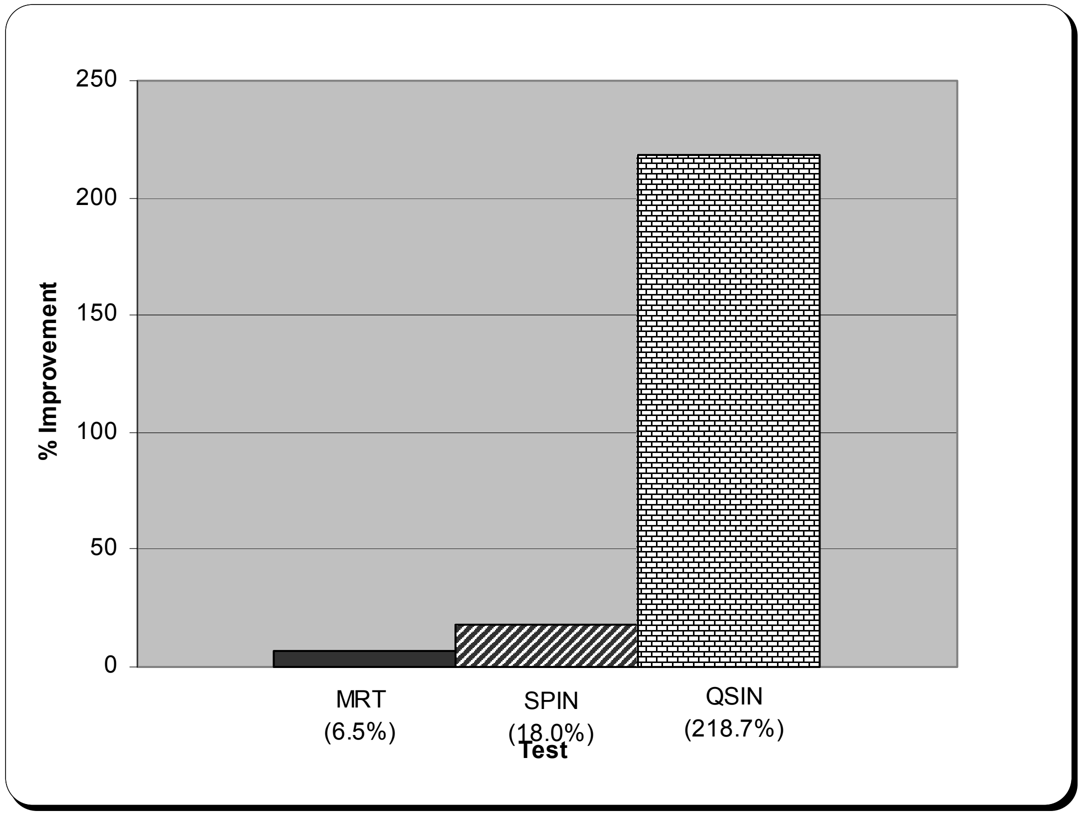

Figure 2.4: Experiment 1: Average Percent Improvement with Processing for Each Speech Intelligibility Test.

CHAPTER 3

METHODS AND RESULTS – EXPERIMENT 2

The objective of Experiment 2 was to confirm that the commercial implementation (CommUnify) of the algorithm resulted in improvement in speech recognition over the telephone and that the improvement achieved with the commercial application was as good as the improvement achieved with the laboratory implementation of the algorithm. The participants, calibration, and procedures used for Experiment 2 are described in this chapter. This is followed by the data processing and results of this experiment.

3.1 Participants

Thirty participants (14 male, 16 female) were recruited for Experiment 2 from The Ohio State University using the Speech and Hearing Clinic database and employee email advertisements. All twenty participants from Experiment 1 agreed to continue in the study and an additional ten were added for Experiment 2. Participants were 55 to 70 years of age, native speakers of English, and had moderate to severe sensorineural hearing loss in at least one ear. Listeners received a free hearing evaluation and a monetary payment for their participation in this experiment.

3.2 Procedures

3.2.1 Forms

Those participants who did not participate in Experiment 1 were given the Consent for Participation in Social and Behavioral Research form (Appendix E) and the Authorization to Use Personal Health Information in Research form (Appendix F) to read and sign prior to testing.

All subjects were reimbursed for their parking and compensated for their time. For the first session, compensation consisted of a free audiological evaluation. For the second session, compensation consisted of a monetary payment given to the subject at the beginning of the test session. All subjects were also required to sign a Payment Record Form (Appendix G) to reflect these reimbursements and compensations.

3.2.2 Stimulus Materials

The Quick Speech-in-Noise Test (QSIN) (Killion et al., 2003), the representative signal-to-noise ratio (SNR) test, was used to complete Experiment 2 because it was determined to be the most effective and efficient speech understanding test in Experiment 1. As previously stated, each QSIN list consists of six sentences with five key words per sentence presented in varying levels of background multi-talker babble (e.g. "<u>Tear</u> a <u>thin</u> <u>sheet</u> from the <u>yellow</u> <u>pad</u>"). The QSIN requires the listener to repeat sentences that he or she hears.

3.2.3 Processing and Delivery of the QSIN

As in Experiment 1, the digitized QSIN lists were stored on a desktop PC hard drive. The Ohio State version of the speech processing algorithm (implemented in MatLab and SimuLink) and the CommUnify speech-processing program were used to process tokens from the selected tests. As in Experiment 1, for the Ohio State version of the algorithm, processed tokens were delivered to the telephone line through a Creative Systems Audigy 2NX sound card and a Gentner telephone coupling device. See Figure 2.1 for details of the laboratory setup. Using the CommUnify version, the digitized items were delivered to the telephone line using the "Phrase Over Phone" program provided by FutureCom for the commercial version of the algorithm. See Figure 3.1 for details of the CommUnify setup.

3.2.4 Calibration

As stated in Chapter 2, the FutureCom CommUnify processing system was used as the "Gold Standard" for calibration of the Ohio State processing system. The signals processed using the Ohio State system were matched to the level of the CommUnify system using the volume control on the Sound Blaster. Single-channel calibration tones were used to avoid doubling of the signal level in the Mixer. Using a sound level meter to measure the level on the listener's telephone, it was determined that the Sound Blaster volume should be set to 42%, as read on the computer screen.

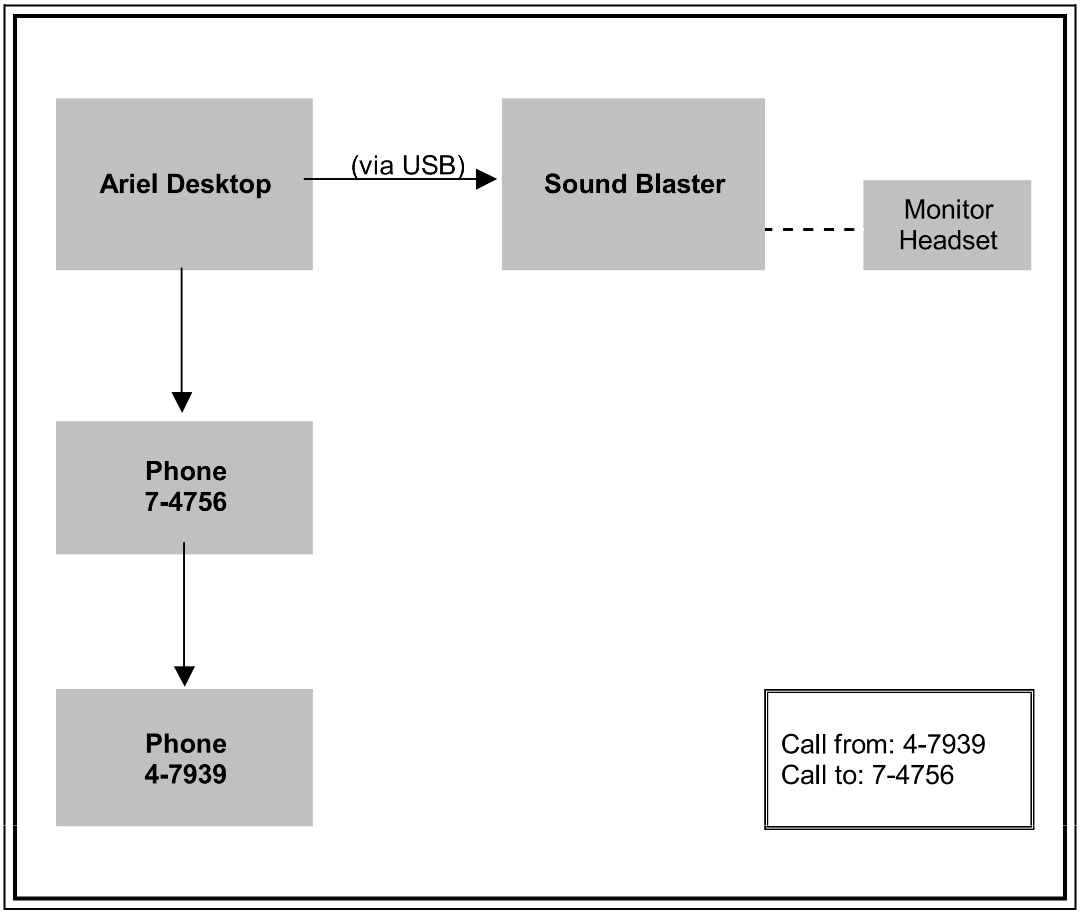

Figure 3.1: Setup for CommUnify Testing for Experiment 2.

3.2.5 Sessions 1 and 2

Testing was completed in the following two sessions:

- **Session 1: Standard Audiological Evaluation.** The twenty participants from Experiment 1 had received audiological evaluations earlier in the study. These results were used to determine eligibility for Experiment 2. All subjects who had not participated in Experiment 1 received a routine audiological evaluation to determine eligibility for this experiment. This evaluation consisted of the following procedures: otoscopy, tympanometry, conventional pure tone audiometry including air and bone conduction thresholds, speech recognition threshold testing, and word recognition testing. All audiometric testing was completed in a sound-treated booth, using standard clinical procedures.
  - Individual audiometric data is shown in Appendix H. An average audiogram from the thirty subjects in Experiment 2 is shown in Figure 3.2.

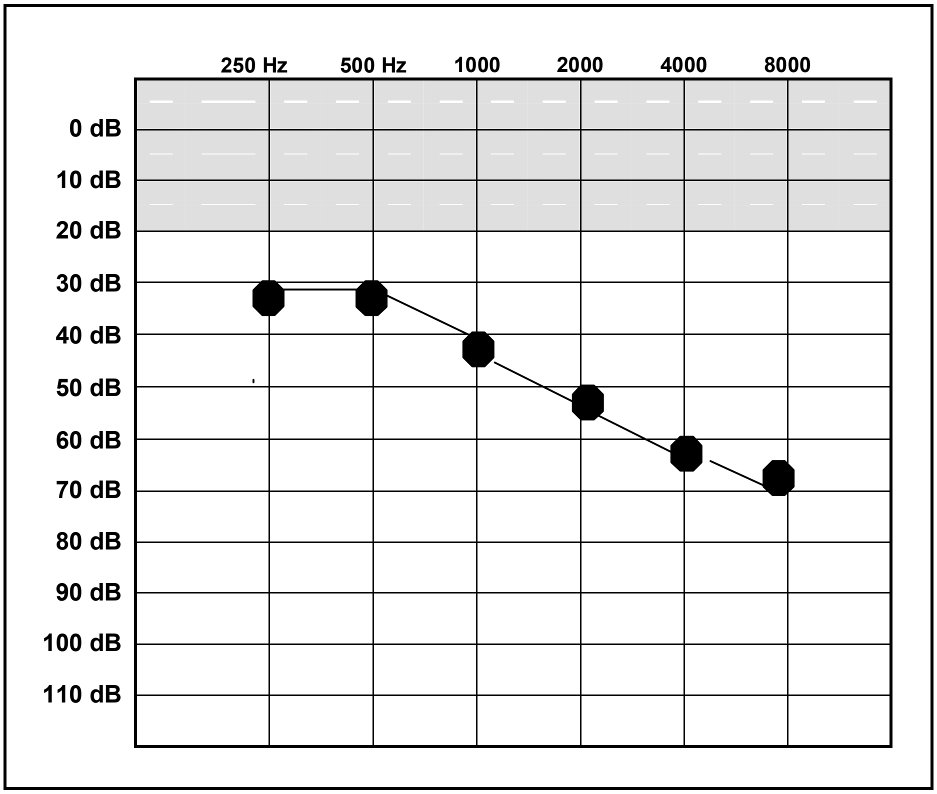

Figure 3.2: Average Audiogram of Experiment 2 Participants (Average of the 30 ears used for experimental testing). Pure tone average (PTA) = 40 dB HL.

- **Session 2: Comparison of Speech Processing Systems.** Once the current hearing abilities of the participants were established, each subject listened to three versions of the QSIN, the speech intelligibility test identified as the most effective in Experiment 1. The three versions were as follows:

    - Unprocessed – the digitized test items delivered to the listener over the phone without additional processing
    - Processed using the **laboratory** system – the digitized test items delivered to the listener over the phone using Ohio State's implementation of the algorithm utilizing MatLab and SimuLink
    - Processed using the **CommUnify** server system – the digitized test items delivered to the listener over the phone using the new algorithm integrated into the commercial signal processing server, CommUnify, Unified Communications Platform, developed by FutureCom Technologies

Testing was completed in the Hearing Aid Research Laboratory in Pressey Hall on The Ohio State University campus. Participants were seated in a sound-treated booth, and stimuli were delivered to a standard telephone receiver over a standard telephone line. The order of presentation mode (unprocessed, laboratory processing, and CommUnify processing) was randomized to prevent order effects.

3.3 Data Processing and Results

3.3.1 Percent Correct: Laboratory Processing vs. CommUnify Processing vs. Unprocessed Presentation

Figure 3.3 shows the average percent correct responses for each of the three conditions, unprocessed, processed with the laboratory version, and processed with the CommUnify version. The average score in the unprocessed condition was 26.4%. The average scores from the laboratory processing condition and CommUnify processing condition were similar, with average scores of 55.1% and 60.4% respectively.

Percent correct scores from each of thirty subjects were arc-sine transformed and analyzed using a one-factor (presentation mode) within-subjects analysis of variance (ANOVA). A significant (defined as an alpha level of ≤ 0.01) main effect of presentation mode was found ($F[2,58] = 81.91$, $p = .000$). Post hoc means comparisons indicated significant differences between the unprocessed condition and laboratory processing condition, and significant differences between the unprocessed condition and CommUnify processing condition. No significant difference was found between the laboratory and CommUnify processing ($p = .04$).

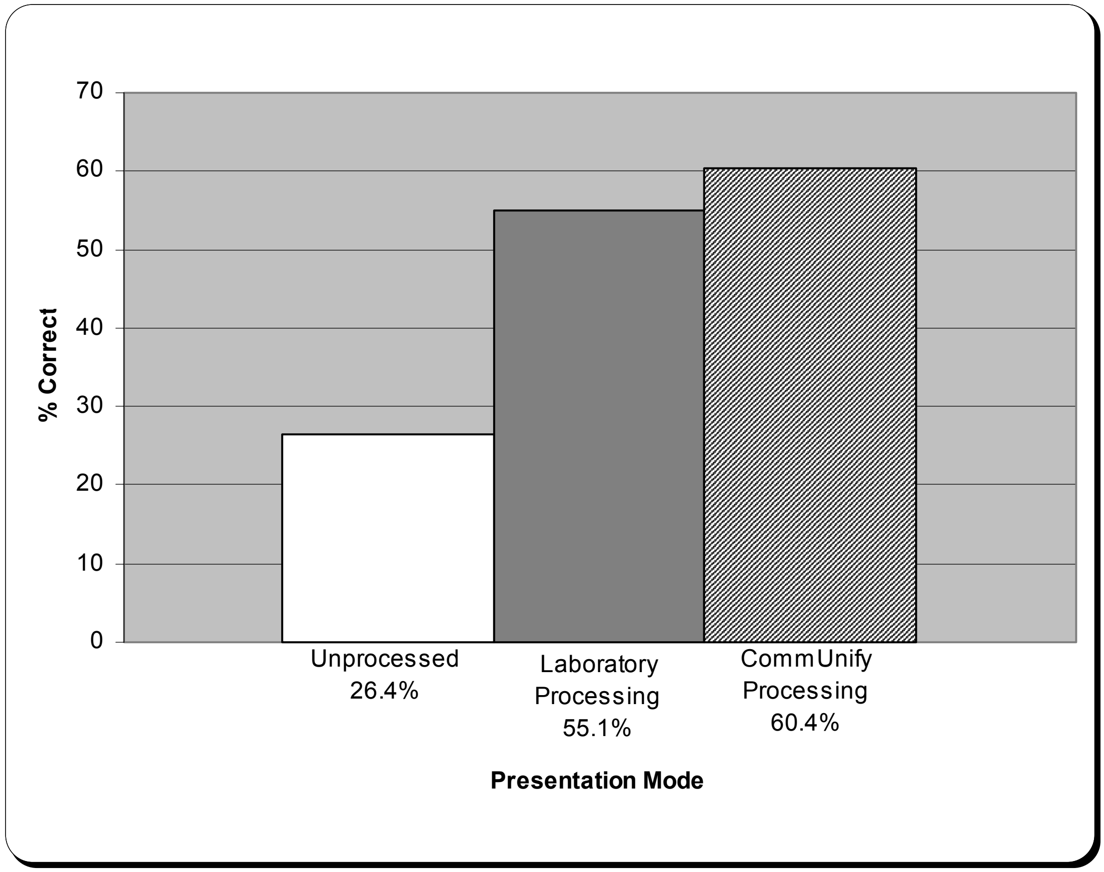

Figure 3.3: Experiment 2: Average Percent Correct Responses for Each Presentation Mode of the QSIN.

3.3.2 Percent Improvement: Laboratory Processing vs. CommUnify Processing

Percent improvement scores were devised for each subject for both processed conditions using the same equation used in Experiment 1. Figure 3.4 shows the average percent improvement scores for each of the two processing conditions. A comparison of average improvement scores in Figure 4 shows that the laboratory and CommUnify processing systems performed similarly.

The percent improvement scores were analyzed using a one-factor (processing condition) within-subjects ANOVA. No significant (defined as an alpha level of ≤ 0.01) difference was found between percent improvement scores for the laboratory version and the CommUnify version of the speech processing algorithm ($F[1,29] = 4.27$, p=.048). These results demonstrated that the commercial version of the algorithm improved speech recognition over the telephone, and this improvement is the same as that achieved using the laboratory version of the algorithm.

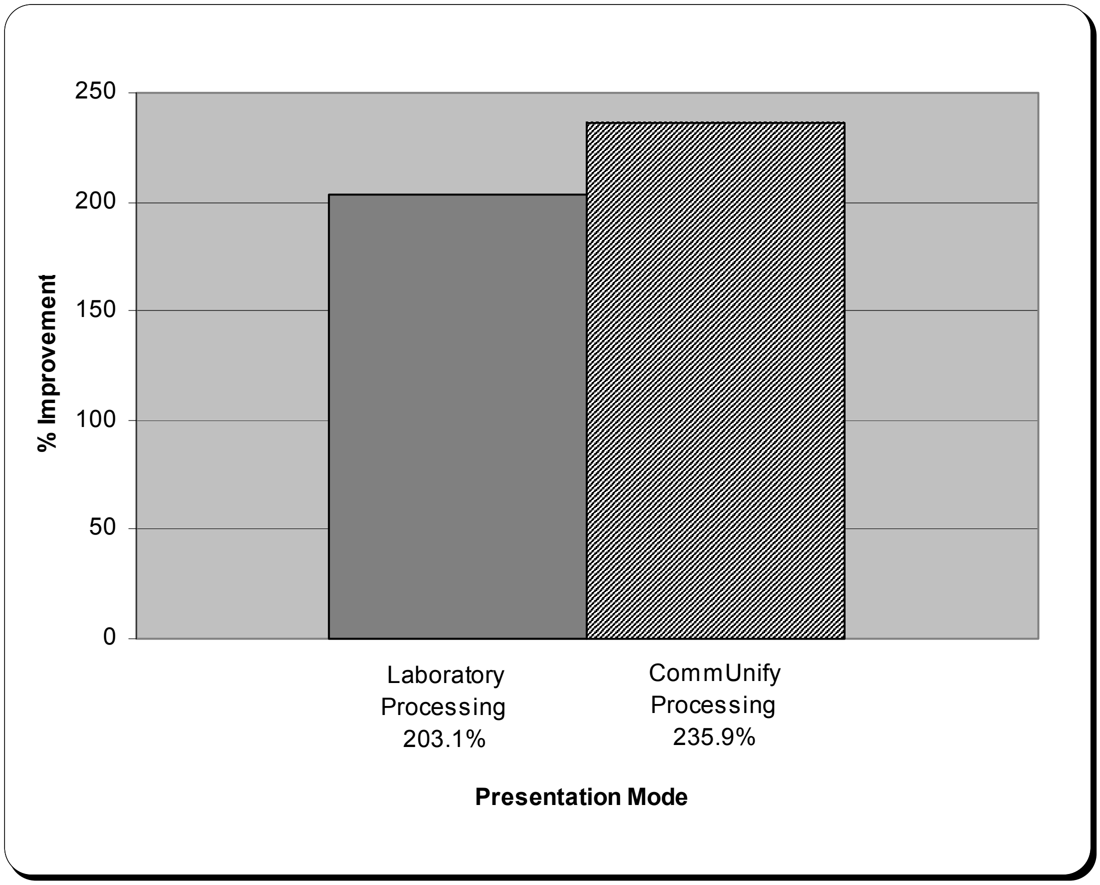

Figure 3.4: Experiment 2. Average Percent Improvement on the QSIN with both processing systems.

CHAPTER 4

DISCUSSION AND CONCLUSIONS

Telephone communication is a significant difficulty faced by many older adults with hearing loss. In addition to the listener's hearing loss, several factors contribute to the difficulties experienced during telephone use, including the limited frequency range available over the telephone, absence of visual cues, line noise present at the receiver, background noise, and monaural listening. The speech enhancement algorithm used in this study was designed to enhance speech perception by pre-processing speech on the talker's end before being sent over the telephone line to the listener with hearing loss. Two objectives were met at the completion of Experiments 1 and 2.

4.1 Summary and Significance of Experiment 1

The goal of Experiment 1 was to determine which type of speech intelligibility test serves as the best tool for evaluating the performance of older adult listeners with sensorineural hearing loss over the telephone. Scores from the unprocessed and processed versions of each of the three speech intelligibility tests (MRT, SPIN, and QSIN) were compared to determine the most effective and/or efficient test for this purpose. The most effective test was defined as the one that best differentiates subjects' performance on unprocessed and processed versions of the test. The most efficient test was defined as the one that was the least time consuming (the SPIN test took the longest at 10 minutes per test; the MRT was next at 6.5 minutes per test, and the QSIN was completed in the least amount of time at 1.5 minutes per test). The results from Experiment 1 indicated that the QSIN test was both most effective (because it best differentiated subjects' performance on the processed and unprocessed versions of the test) and most efficient (because it could be completed in the least amount of time).

The results of Experiment 1 indicated that the QSIN is an effective and efficient tool for evaluating the performance of older adult listeners with hearing loss on the telephone. Thus, the QSIN was used in Experiment 2.

4.2 Summary and Significance of Experiment 2

Experiment 2 confirmed that the commercial implementation of the algorithm resulted in improvement in speech recognition over the telephone and that the improvement achieved with the commercial application was equivalent to the improvement achieved with the laboratory implementation of the algorithm, satisfying Objective 3 of the Phase 1 project.

4.3 Future Work and Research

Previous work and research involving the speech processing algorithm has been promising. Not only has the algorithm been shown to aid in speech perception of older adults over the telephone, FutureCom Technologies Inc. successfully integrated the algorithm into a commercial signal processing server platform, the CommUnify platform.

Due to these positive results, FutureCom Technologies and The Ohio State University plan to continue this work and research. Future objectives for the Phase II project include improvements and adaptations to the original algorithm, development of a real-time speech enhancement system, and testing of the commercial implementation of the system.

Gokcen (2006) of FutureCom Technologies proposed several factors for investigation in the Phase II project for improvement of the original speech enhancement algorithm in order to determine if adaptations need to be made to the algorithm. First, research will be conducted to evaluate any additional benefit of incorporating multiple hearing loss configurations, as compared to the current single audiogram format. Second, because research thus far has been conducted using standard land-line telephones, the algorithm will be tested on other types of telephones, including cell phones and VoIP phones to determine if the performance of the algorithm deteriorates when the input and output is distorted by the coding of these phones. If the algorithm's performance does degrade, compensatory strategies will be implemented and assessed. Finally, research will assess the effects of different speakers, both male and female, and necessary adaptations will be made to the algorithm and tested (Gokcen, 2006).

In addition to the aforementioned investigations and possible adaptations planned for Phase II, FutureCom Technologies plans to develop a real-time version of the speech processing system utilizing the CommUnify Unified Communications Platform. The goal is for this version to be used in a commercial telephone network environment with multiple simultaneous live conversations. Following the development of the commercial speech enhancement system, it will be tested first by simulating a commercial site and then at a real commercial site (Gokcen, 2006).

In addition to the Phase II objectives discussed above, additional research should be conducted to address the ceiling effects found for the MRT and SPIN tests in the unprocessed conditions of Experiment 1. Because participants' percent correct scores were high in the unprocessed condition, little room was left for improvements in the processed conditions. It is possible that the QSIN showed the most improvement with processing due to this factor. Therefore, a fair comparison needs to be made between the SPIN, MRT, and QSIN tests. This may be accomplished by adding multi-talker babble to the SPIN sentences and the MRT in both the unprocessed and processed conditions. By doing this, the SPIN and MRT may become more similar to the QSIN in terms of difficultly in the unprocessed conditions, thus leading to the alleviation of the ceiling effects of these tests. Following this future research, the most appropriate speech intelligibility test should be chosen for the evaluation of speech understanding of older adult listeners with hearing loss over the telephone, confirming or refuting the results of Experiment 1 in the present study.

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APPENDIX A

RECRUITMENT LETTER

Department of Speech & Hearing Science

110 Pressey Hall
1070 Carmack Rd.
Columbus, OH 43210

Phone 614-292-8207
FAX 614-292-7504

Dear _______________:

This letter is to inform you that according to our records, you may qualify for a study we are conducting with hearing impaired clients. This research study will be conducted by a doctoral student and Dr. Stephanie Davidson Strang, Ph.D., associate professor.

The purpose of this study is to look at ways to help people with hearing loss use the telephone. We know that listening to other people on the telephone can be very difficult when a person has a hearing loss. In this study, you would listen to words and sentences through a regular telephone handset and repeat the words that you hear. If you are interested in participating in this study, we ask you to come in for a total of 3 sessions (approximately 2 hours each). The first session is devoted to a free hearing test to establish candidacy in the study. If you elect to participate, you receive $20.00 to cover transportation costs at the second session and $20.00 for attending the final session

The research will take place at The Ohio State University Speech-Language-Hearing Clinic and departmental research labs in Pressey Hall (141 Pressey Hall, 1070 Carmack Road, Columbus, OH 43210). Each session will be scheduled according to your availability, as well as the availability of the investigator.

One of our doctoral candidates will call you to answer any questions you may have and to set-up an appointment if you are interested in participating in this study.

Sincerely,

____
Stephanie Davidson Strang, Ph.D.
Professor, OSU Speech & Hearing Science Department

____
Gail Whitelaw, Ph.D.
Director, OSU Speech-Language-Hearing Clinic

APPENDIX B

ORAL SCRIPTS

ORAL SCRIPTS

Script for contacting potential study participants via the telephone:

Hello, my name is ____________________ and I am calling from The Ohio State University Department of Speech and Hearing Science. I am following up on a letter that was sent to you in the mail notifying you that you may qualify for a study we are conducting looking at ways to help people with hearing loss use the telephone. We know that listening to other people on the telephone can be very difficult when a person has a hearing loss.

In this study, you would listen to words and sentences through a regular telephone handset and report the words that you hear. If you are interested in participating in this study, we ask you to come in for a total of 3 sessions (approximately 2 hours each). The first session is devoted to a free hearing test. You receive $20.00 at the second session to cover transportation costs and $20.00 for attending the final session.

Do you have any questions for me at this time?

If you think you are interested in participating, I can go ahead and schedule an appointment with you. At that appointment, I can further explain the study and test your hearing. As I mentioned, the appointment should last about 2 hours.

Thank you for you help and your time.

Script for being contacting by potential study participants:

Thank you for getting in touch with me. As you may know, I am involved in a study at The Ohio State University Department of Speech and Hearing Science looking at ways to help people with hearing loss use the telephone. We know that listening to other people on the telephone can be very difficult when a person has a hearing loss.

In this study, you would listen to words and sentences through a regular telephone handset and report the words that you hear. If you are interested in participating in this study, we ask you to come in for a total of 3 sessions (approximately 2 hours each). The first session is devoted to a free hearing test. You receive $20.00 at the second session to cover transportation costs and $20.00 for attending the final session.

Do you have any questions for me at this time?

If you think you are interested in participating, I can go ahead and schedule an appointment with you. At that appointment, I can further explain the study and test your hearing. As I mentioned, the appointment should last about 2 hours.

Thank you for your help and your time.

APPENDIX C

EMAIL RECRUITMENT ADVERTISEMENT

Recruitment Advertisement (OSU Today/Weekly):

If you have hearing loss, are 55 to 70 years of age, and a native speaker of English, you may qualify for a research study of speech understanding over the telephone. Participants will receive a free hearing evaluation and may earn up to $40 in three 1-hour sessions. To volunteer for this study, please contact the Department of Speech and Hearing Science at harhager.2@osu.edu. Please indicate that you are interested in participating in Kim's telephone research project.

APPENDIX D

RECRUITMENT FLYER

The Ohio State University Speech-Language-Hearing Clinic

FREE HEARING TEST

& EARN UP TO $40 IN TWO 2-HOUR SESSIONS

If you have hearing loss, are 60-70 years of age
& a native speaker of English,
you may qualify
for a research study of speech understanding over the telephone.

To volunteer for this study, please contact Kim at

(614) 226-6353

Telephone Study
Contact Kim: 614-226-6353

Telephone Study
Contact Kim: 614-226-6353

Telephone Study
Contact Kim: 614-226-6353

Telephone Study
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Telephone Study
Contact Kim: 614-226-6353

APPENDIX E

CONSENT FOR PARTICIPATION IN RESEARCH

THE OHIO STATE UNIVERSITY

Department of Speech & Hearing Science

110 Pressey Hall
1070 Carmack Rd.
Columbus, OH 43210

Phone 614-292-8207
FAX 614-292-7504

CONSENT FOR PARTICIPATION IN SOCIAL AND BEHAVIORAL RESEARCH

Protocol title: Evaluation of Speech Processing for Telephone Use by Elderly Hearing Impaired Listeners

Protocol number: 2004B0166
Principal Investigator: Stephanie Davidson Strang, Ph.D.

I consent to my participation in research being conducted by Stephanie Davidson Strang of the Department of Speech and Hearing Science at The Ohio State University and her assistants and associates.

The investigator(s) has explained the purpose of the study, the procedures that will be followed, and the amount of time it will take. I understand the possible benefits, if any, of my participation.

I know that I can choose not to participate without penalty to me. If I agree to participate, I can withdraw from the study at any time, and there will be no penalty.

I have had a chance to ask questions and to obtain answers to my questions. I can contact the investigators at (614) 292-8207. If I have questions about my rights as a research participant, I can call the Office of Research Risks Protection at (614) 688-4792.

I have read this form or I have had it read to me. I sign it freely and voluntarily. A copy has been given to me.

Print the name of the participant:

____

Date: ______________________________

Signed: ______________________________
(Participant)

Signed: ______________________________
(Principal Investigator or his/her authorized representative)

Signed: ______________________________
(Person authorized to consent for participant, if required)

Witness: ______________________________
(When required)

HS-027 (Rev. 05/01)

APPENDIX F

AUTHORIZATION TO USE PHI IN RESEARCH

THE OHIO STATE UNIVERSITY

AUTHORIZATION TO USE

PERSONAL HEALTH INFORMATION IN RESEARCH

Title of the Study: Evaluation of Speech Processing for Telephone Use by Elderly Listeners with Hearing Loss

OSU Protocol Number: 2004B0166

Principal Investigator: Stephanie Davidson Strang, Ph.D.

Subject Name____

Before researchers use or share any health information about you as part of this study, The Ohio State University is required to obtain your authorization. This helps explain to you how this information will be used or shared with others involved in the study.

- The Ohio State University and its hospitals, clinics, health-care providers and researchers are required to protect the privacy of your health information.
- You should have received a Notice of Privacy Practices when you received health care services here. If not, let us know and a copy will be given to you. Please carefully review this information. Ask if you have any questions or do not understand any parts of this notice.
- If you agree to take part in this study your health information will be used and shared with others involved in this study. Also, any new health information about you that comes from tests or other parts of this study will be shared with those involved in this study.
- Health information about you that will be used or shared with others involved in this study may include your research record and any health care records at the Ohio State University. For example, this may include your medical records, x-ray or laboratory results. Psychotherapy notes in your health records (if any) will not, however, be shared or used. Use of these notes requires a separate, signed authorization.

Please read the information carefully before signing this form. Please ask if you have any questions about this authorization, the University's Notice of Privacy Practices or the study before signing this form.

Initials/Date: _______________

Those Who May Use, Share And Receive Your Information As Part Of This Study

- Researchers and staff at The Ohio State University will use, share and receive your personal health information for this research study. Other Ohio State University staff not involved in the study but who may become involved in your care for study-related treatment will have access to your information.
- Those who oversee the study will have access to your information, including:
    - Members and staff of the Ohio State University's Institutional Review Boards, including the Western Institutional Review Board
    - The Office for Responsible Research Practices
    - University data safety monitoring committees
    - The Ohio State University Research Foundation
- Your health information may also be shared with federal and state agencies that have oversight of the study or to whom access is required under the law. These may include:
    - The Food and Drug Administration
    - The Office for Human Research Protections
    - The National Institutes of Health
    - The Ohio Department of Human Services
- These researchers, companies and/or organization(s) outside of The Ohio State University may also use, share and receive your health information in connection with this study:

    - Your information may also be shared with FutureCom Technologies Inc. This information may include demographic information, hearing loss, and test results.

Initials/Date__________ _____

Authorization Period

This authorization will not expire unless you change your mind and revoke it in writing. There is no set date at which your information will be destroyed or no longer used. This is because the information used and created during the study may be analyzed for many years, and it is not possible to know when this will be complete.

Signing the Authorization

- You have the right to refuse to sign this authorization. Your health care outside of the study, payment for your health care, and your health care benefits will not be affected if you choose not to sign this form.
- You will not be able to take part in this study and will not receive any study treatments if you do not sign this form.
- If you sign this authorization, you may change your mind at any time. Researchers may continue to use information collected up until the time that you formally changed your mind. If you change your mind, your authorization must be revoked in writing. To revoke your authorization, please write to:

  Stephanie Davidson Strang, Ph.D., strang.7@osu.edu, (614) 292-1802

  Or Gail Whitelaw, Ph.D., Whitelaw.1@osu.edu, (614) 292-6251
- Signing this authorization also means that you will not be able to see or copy your study-related information until the study is completed. This includes any portion of your medical records that describes study treatment.

Contacts for Questions

- If you have any questions relating to your privacy rights, please contact Gail Whitelaw, Ph. D., Whitelaw.1@osu.edu, (614) 292-6251.
- If you have any questions relating to the research, please contact Stephanie Davidson Strang, Ph.D., strang.7@osu.edu, (614) 292-1802

Signature

I have read (or someone has read to me) this form and have been able to ask questions. All of my questions about this form have been answered to my satisfaction. By signing below, I permit *[insert name of Principal Investigator]* and the others listed on this form to use and share my personal health information for this study. I will be given a copy of this signed form.

Signature____
(Subject or Legally Authorized Representative)

Name ____
(Print name above)
(If legal representative, also print relationship to subject.)

Date__________ Time _________ AM / PM

APPENDIX G

PAYMENT RECORD FORM

THE OHIO STATE UNIVERSITY

Department of Speech & Hearing Science

110 Pressey Hall
1070 Carmack Rd.
Columbus, OH 43210
Phone 614-292-8207
FAX 614-292-7504

Subject Payment Record

Protocol title: Evaluation of Speech Processing for Telephone Use by Elderly Hearing Impaired Listeners
Protocol number: 2004B0166
Principal Investigator: Stephanie Davidson Strang, Ph.D.
Co-Investigator: Kimberly Harhager

Subject Name:____
Social Security Number:__________________________

Session #1

Date:______________

Parking Meter:
Amount Paid: $__________

Compensation for participation:
Free Hearing Test — Subject's Signature: ________________________

Session #2

Date:______________

Parking Meter:
Amount Paid: $__________

Compensation for participation:
Amount Paid: $ 20.00 — Subject's Signature: ________________________

Session #3

Date:______________

Parking Meter:
Amount Paid: $__________

Compensation for participation:
Amount Paid: $ 20.00 — Subject's Signature: ________________________

APPENDIX H

INDIVIDUAL AUDIOMETRIC DATA

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**55**	**45**	**45**	**65**	**80**	**100**	52	50	84
Left	**50**	**55**	**55**	**75**	**80**	**85**	62	55	78

Table H.1: Audiometric Data from Subject 1.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**35**	**40**	**55**	**60**	**65**	**70**	52	55	86
Left	**25**	**40**	**50**	**55**	**60**	**65**	48	55	88

Table H.2: Audiometric Data from Subject 2.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**35**	**65**	**65**	**80**	**75**	55	65	78
Left	**15**	**25**	**55**	**65**	**80**	**70**	48	55	74

Table H.3: Audiometric Data from Subject 3.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**15**	**10**	**70**	**75**	**85**	50	35	92
Left	**25**	**20**	**20**	**75**	**80**	**85**	58	40	92

Table H.4: Audiometric Data from Subject 4.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**25**	**35**	**40**	**50**	**55**	35	35	100
Left	**20**	**25**	**35**	**35**	**50**	**50**	32	35	96

Table H.5: Audiometric Data from Subject 5.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**20**	**40**	**45**	**45**	**60**	35	40	92
Left	**20**	**20**	**35**	**45**	**55**	**60**	33	40	92

Table H.6: Audiometric Data from Subject 6.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**35**	**35**	**55**	**60**	**75**	**65**	52	60	82
Left	**40**	**30**	**45**	**60**	**70**	**95**	45	45	88

Table H.7: Audiometric Data from Subject 7.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**50**	**50**	**50**	**50**	**55**	**90**	50	60	92
Left	**50**	**45**	**50**	**55**	**50**	**80**	50	60	96

Table H.8: Audiometric Data from Subject 8.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**40**	**45**	**45**	**50**	**55**	**85**	47	45	80
Left	**50**	**55**	**55**	**65**	**75**	**85**	58	50	78

Table H.9: Audiometric Data from Subject 9.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**45**	**40**	**30**	**40**	**60**	**75**	38	40	100
Left	**25**	**20**	**20**	**30**	**60**	**75**	23	25	96

Table H.10: Audiometric Data from Subject 10.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**35**	**20**	**30**	**85**	**95**	**100**	45	35	80
Left	**20**	**20**	**20**	**75**	**80**	**95**	38	30	76

Table H.11: Audiometric Data from Subject 11.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**20**	**35**	**50**	**60**	**85**	35	40	96
Left	**30**	**25**	**45**	**55**	**70**	**90**	40	45	96

Table H.12: Audiometric Data from Subject 12.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**10**	**20**	**60**	**55**	**20**	30	25	88
Left	**10**	**10**	**20**	**55**	**55**	**20**	28	25	100

Table H.13: Audiometric Data from Subject 13.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**25**	**30**	**35**	**35**	**50**	**80**	33	35	90
Left	**25**	**30**	**40**	**40**	**55**	**70**	37	40	92

Table H.14: Audiometric Data from Subject 14.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**20**	**40**	**30**	**25**	**25**	30	25	96
Left	**15**	**60**	**60**	**50**	**35**	**25**	57	45	88

Table H.15: Audiometric Data from Subject 15.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**20**	**40**	**45**	**45**	**75**	35	35	88
Left	**25**	**30**	**30**	**50**	**50**	**80**	37	35	92

Table H.16: Audiometric Data from Subject 16.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**35**	**55**	**55**	**50**	**25**	**10**	53	55	92
Left	**50**	**65**	**55**	**45**	**45**	**5**	55	60	96

Table H.17: Audiometric Data from Subject 17.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**30**	**25**	**15**	**50**	**50**	**55**	30	35	88
Left	**35**	**30**	**10**	**45**	**45**	**35**	32	30	96

Table H.18: Audiometric Data from Subject 18.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**20**	**25**	**35**	**60**	**65**	**50**	38	25	75
Left	**25**	**20**	**35**	**65**	**65**	**60**	40	25	82

Table H.19: Audiometric Data from Subject 19.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**10**	**15**	**20**	**40**	**50**	**65**	25	25	96
Left	**10**	**15**	**25**	**25**	**40**	**60**	22	20	100

Table H.20: Audiometric Data from Subject 20.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**25**	**35**	**40**	**40**	**60**	**65**	38	35	92
Left	**20**	**30**	**40**	**45**	**70**	**60**	38	35	92

Table H.21: Audiometric Data from Subject 21.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**40**	**45**	**50**	**20**	**20**	**30**	38	25	96
Left	**20**	**20**	**25**	**35**	**45**	**40**	27	25	100

Table H.22: Audiometric Data from Subject 22.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**40**	**45**	**50**	**60**	**65**	**85**	52	50	68
Left	**30**	**40**	**45**	**55**	**65**	**90**	47	50	62

Table H.23: Audiometric Data from Subject 23.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**35**	**30**	**50**	**55**	**45**	**55**	45	45	96
Left	**35**	**35**	**55**	**60**	**50**	**60**	50	45	92

Table H.24: Audiometric Data from Subject 24.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**15**	**15**	**35**	**65**	**70**	22	20	96
Left	**15**	**15**	**10**	**20**	**40**	**60**	15	10	96

Table H.25: Audiometric Data from Subject 25.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**40**	**35**	**45**	**45**	**75**	**65**	42	40	92
Left	**60**	**50**	**35**	**35**	**80**	**70**	40	45	88

Table H.26: Audiometric Data from Subject 26.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**25**	**40**	**50**	**55**	**75**	38	35	88
Left	**20**	**25**	**35**	**45**	**60**	**75**	35	35	92

Table H.27: Audiometric Data from Subject 27.
Ear used during experimental testing: Left.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**15**	**20**	**35**	**50**	**50**	23	20	92
Left	**10**	**15**	**15**	**35**	**50**	**55**	22	25	88

Table H.28: Audiometric Data from Subject 28.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**15**	**10**	**20**	**40**	**40**	**65**	23	20	96
Left	**15**	**15**	**20**	**35**	**40**	**60**	23	20	96

Table H.29: Audiometric Data from Subject 29.
Ear used during experimental testing: Right.

	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	PTA	SRT	W.R. (%)
Right	**10**	**15**	**20**	**30**	**35**	**40**	22	20	96
Left	**10**	**15**	**15**	**30**	**35**	**45**	20	20	92

Table H.30: Audiometric Data from Subject 30.
Ear used during experimental testing: Right.

APPENDIX I

INDIVIDUAL SCORES FROM EXPERIMENT 1

Subject #	Unprocessed % Correct	Processed % Correct	% Improvement
1	76	82	7.89
2	92	88	-4.35
3	80	78	-2.50
4	78	84	7.69
5	92	90	-2.17
6	86	88	2.32
7	74	86	16.22
8	78	84	7.69
9	64	80	25.00
10	92	92	0
11	82	76	-7.32
12	72	80	11.11
13	78	98	25.64
14	84	90	7.14
15	74	64	-13.51
16	86	90	4.65
17	68	80	17.65
18	90	88	-2.22
19	72	90	25.00
20	92	96	4.00

Table I.1: Individual Scores from Experiment 1 on the MRT.

Subject #	Unprocessed % Correct	Processed % Correct	% Improvement
1	58	72	24.14
2	76	90	18.42
3	44	64	45.45
4	68	72	5.88
5	88	98	11.36
6	80	94	17.5
7	64	82	28.13
8	76	80	5.26
9	54	62	14.81
10	94	96	2.13
11	78	90	15.38
12	56	76	35.71
13	88	98	11.36
14	86	94	9.30
15	48	62	29.17
16	86	80	-6.97
17	42	58	38.10
18	70	78	11.43
19	64	88	38.00
20	86	90	5.00

Table I.2: Individual Scores from Experiment 1 on the SPIN.

Subject #	Unprocessed % Correct	Processed % Correct	% Improvement
1	10	30	200.00
2	33	83	151.52
3	17	30	76.47
4	30	30	0
5	23	63	173.91
6	23	67	191.30
7	3	47	1466.67
8	23	60	160.87
9	10	33	230.00
10	57	93	63.16
11	13	27	107.69
12	23	87	278.26
13	23	67	191.30
14	30	83	176.67
15	10	63	530.00
16	43	70	38.57
17	13	37	184.62
18	50	67	34.00
19	27	37	37.00
20	33	60	82.00

Table I.3: Individual Scores from Experiment 1 on the QSIN.

APPENDIX J

INDIVIDUAL SCORES FROM EXPERIMENT 2

Subject #	Unprocessed % Correct	Laboratory Processing		CommUnify Processing	
		% Correct	% Improvement	% Correct	% Improvement
1	13	23	76.92	50	284.62
2	33	53	60.61	73	121.21
3	7	13	85.71	27	285.71
4	20	37	85.00	47	135.00
5	43	83	93.02	93	116.28
6	27	87	222.22	87	222.22
7	10	50	400.00	50	400.00
8	37	67	81.08	53	43.24
9	7	40	471.43	50	614.29
10	70	97	38.57	93	32.86
11	33	60	81.82	50	51.52
12	30	80	166.67	77	156.67
13	57	77	35.09	97	70.18
14	53	90	69.81	93	75.47
15	7	57	714.28	47	571.43
16	57	70	22.81	83	45.61
17	7	37	428.57	53	657.14
18	30	67	123.33	67	123.33
19	33	67	103.03	80	142.42
20	37	70	89.19	93	151.35
21	17	40	135.3	67	294.12
22	70	97	38.57	97	38.57
23	7	47	571.43	37	428.57
24	7	60	757.14	63	800.00
25	20	70	250.00	73	265.00
26	11	20	81.82	17	54.54
27	3	22	633.33	25	733.33
28	17	26	52.94	25	47.06
29	16	25	56.25	25	56.25
30	12	20	66.77	19	58.33

Table J.1: Individual Scores from Experiment 2 on QSIN.